Addendum: GLIMPSE Validation Report

The GLIMPSE Team

August 18, 2004

1. Motivation

In our Validation Report of Jan. 30, 2004, we produced reliability calculations and discussed photometric accuracy estimates based on Observing Strategy Validation (OSV) data and an early version of the GLIMPSE post-BCD pipeline reduction package. We showed that GLIMPSE could produce a catalog of point sources with reliability $\geq$99.5% and photometric accuracies better than 0.2 mag in all IRAC bands if we excluded regions of complex diffuse background emission >56 MJy/str (>1.9 mJy/pixel) in IRAC band [8.0]. However, we noted that we were experimenting with source extraction techniques that had the potential to more reliably extract point sources in bright and spatially variable diffuse emission regions. In the meantime, the GLIMPSE team has developed a robust extraction technique that delivers high reliablity, completeness, and photometric accuracy using only two observations per IRAC band of each point in the GLIMPSE survey area with no restrictions on diffuse emission brightness level. The GLIMPSE post-BCD pipeline now provides high quality results over the entire range of diffuse emission brightness and stellar densities encountered in the OSV field. We report the results of these developments here in the form of amended reliability and photometric accuracy plots. The two key developments are: 1) implementation in the GLIMPSE point source extractor of an iterative median smoothing of diffuse emission; and, 2) changing the criterion for the internal truth table from 8 detections in a band or an adjacent band to 7 detections in a band or an adjacent band ("7 or 7" criterion).

2. Reliability of the GLIMPSE Point Source Catalog (GPSC)

The reliability plots shown in Figure 1 include the entire OSV region with no restrictions on diffuse emission or source density. Sources were excluded if they were: fainter than 3σ; within the 3 edge pixels of a frame; in column pull-down or banded regions; or in the wings of saturated sources. The criterion for the internal truth table is 7 detections in a given band or an adjacent band. The selection criterion for including a source in the *GLIMPSE Point Source Catalog* (GPSC) is two detections in a given band and at least one detection in an adjacent band (2+1 criterion). The (2+1) selection criterion for the GPSC is a more stringent criterion than the (7 or 7) criterion for the internal truth table. This is illustrated by the fact that the (2+1) criterion selects only about 66 to 67% of the sources in the truth tables of bands [3.6] and [4.5] as defined by the 7 or 7 criterion. The total number of point sources in the analysis shown in Fig. 1 were: [3.6] $\sim$41,140; [4.5] $\sim$37,660; [5.8] $\sim$11,475; and [8.0] $\sim$2004. From Figure 1 we infer that the flux density (mag) limits above which reliability is $\geq$99.5% is achieved in each band is: [3.6] >0.6 mJy (<14.2 mag); [4.5] >0.4 mJy (<14.1 mag); [5.8] >2 mJy (<11.9 mag); and [8.0] >10 mJy (<9.5 mag).

3. Completeness of the GLIMPSE Point Source Archive (GPSA)

Since undetected true sources are not included in an internal truth table, internal completeness cannot be accurately assessed by comparison with an internal truth table. To assess the completeness of the GPSC and GPSA we must either compare with a reliable model that predicts the number of stars in a given area of the Galaxy or with an observed catalog that has similar spatial resolution, sensitivity, and wavelength coverage. The models we are aware of have been developed based on IRAS, MSX, and COBE/DIRBE, none of which have the combination of sensitivity, spatial resolution, and wavelength coverage that Spitzer/IRAC provide. 2MASS and IRAC have about the same resolution and sensitivity but 2MASS bands do not overlap with any of the IRAC bands. There does not seem to be a legitimate way to assess the completeness of either the GPSC or GPSA at this time. The GPSA has about a factor of two more sources in the OSV region than 2MASS. This would seem to indicate that the GPSA is at least as complete as 2MASS, although differences in sensitivity, dynamic range, spatial resolution, and interstellar extinction, as well as stellar colors and other issues have not been considered in assessing the differences in source counts in the two databases.

4. Photometric Accuracy

The document entitled "GLIMPSE Legacy Science and Data Products " (submitted to SSC in Nov. 2003) argued that point source photometry accurate to 0.2 mag is necessary to produce color-magnitude and color-color diagrams of sufficient accuracy for quantitative analyses. To assess our photometric accuracy we have inserted point sources of known magnitude over a wide range of magnitudes into OSV residual images (OSV images with point sources removed). This permitted us to compare the true magnitudes with magnitudes extracted by the GLIMPSE pipeline in the presence of actual diffuse emission structure observed by Spitzer/IRAC.

Because of the high density of point sources in many of the OSV and GLIMPSE fields, inserting known point sources randomly into the raw images, as is normally done, would have pushed us into the confusion limit if we inserted enough sources to give good statistics. The effect of this would be to have inserted sources falling on top of or very close to real sources, thereby confusing the issue between photometric accuracy and confusion problems. To keep these two issues separate, we have choosen to insert sources of known flux into residual images. Known sources will be randomly inserted into low density raw GLIMPSE images to further test our photometric accuracy in the future when we have more fields available and when we are not working toward a delivery deadline.

In Figures 2, 3, 4, and 5, we show differences between the true magnitudes and GLIMPSE extracted magnitudes as a function of magnitude for: 1) all regions; 2) regions with relatively uniform background (i.e. variations of $<$30% over tens of pixels or background levels below $\sim$2-5 MJy/str in IRAC [3.6] and [4.5] and below $\sim$10-20 MJy/str in [5.8] and [8.0]); and, 3) regions of complex background (i.e. variations $>$30% over a few pixels and background levels above $\sim$2-5 MJy/str in IRAC [3.6] and [4.5] and above $\sim$10-20 MJy/str in [5.8] and [8.0]). Complex background regions comprise $<$5% of the GLIMPSE survey area. The 0.2 mag (5σ) error levels are indicated by dashed lines. We give in Table 1 the magnitude limit at which $\leq$10% of the sources in a given magnitude bin exceed the 0.2 mag limit. Figure 2 shows that sources in uniform background regions in band [3.6] are well below the 0.2 mag (5σ) limit down to $\sim$14 mag; in complex background regions to $\sim$13.5 mag; and, in all OSV background regions to $\sim 14^{th}$ mag. Fig. 3 shows that in band [4.5], the photometric accuracy requirement is met for sources in all regions to $\sim$12.0 mag, those in uniform background regions to $\sim$13.5 mag, and in complex backgrounds to $\sim 12^{th}$ mag. Similarly, for band [5.8], Fig. 4 shows that the photometric accuracy requirement is met for all sources to $\sim$10.5 mag, in uniform background regions to $\sim$11.5 mag, and in complex background regions to $\sim 10^{th}$ mag. And Fig. 5 shows that band [8.0] satisfies the photometric accuracy requirement for sources in all background levels to $\sim$9 mag, uniform backgrounds to $\sim$11.5 mag, and complex backgrounds to $\sim$8.5 mag.

The stellar densities span the whole range encountered in the OSV region ($\leq$10 to $\sim$100 arcmin^{-2} in band [3.6] which has the highest source density of all IRAC bands). Typical densities averaged over entire frames in the OSV region are $\sim$30 arcmin^{-2} in band [3.6] with typical individual frames ranging from $\sim$10 to 40 sources arcmin^{-2}, $\sim$20 arcmin^{-2} in [4.5] with typical frames ranging from 10 to 29 sources arcmin^{-2}, $\sim$6 arcmin^{-2} in [5.8] with frames ranging from 3 to 9 sources arcmin^{-2} , and $\sim$6 arcmin^{-2} in [8.0] with frames ranging from 1 to 23 sources arcmin^{-2}.

Another measure of the GLIMPSE photometric accuracy is given by comparing the

GLIMPSE extracted flux densities of our network of flux calibrators with those predicted by Martin Cohen based on Kurucz model atmospheres. These are single stars with well determined spectral types and luminosity classes that span a wide range of fluxes in each IRAC band. Figure 6 shows the Cohen fluxes plotted against the GLIMPSE extracted fluxes for calibration stars in GLIMPSE survey segment l = 305-322 degrees for each IRAC band. The error bars are 1σ for the GLIMPSE data and those for the predicted fluxes are from Cohen (private communication). The vertical lines indicate the point source IRAC saturation limits. Near or above the saturation limits, the GLIMPSE fluxes begin to deviation slightly from Cohen's predicted fluxes, but below these limits the agreement between GLIMPSE and Cohen fluxes are in excellent agreement. The average percent deviation between GLIMPSE and Cohen fluxes are about 5% or less.

5. Summary

The OSV data have been reanalyzed with a substantially modified GLIMPSE point source extractor to determine reliability and photometric accuracy. The GLIMPSE pipeline has been modified since the initial Validation report of 30 Jan. 2004 in several respects to alleviate problems with point source extraction in bright and spatially variable diffuse emission regions and in crowded stellar fields. We have demonstrated that the GLIMPSE Point Source Catalog can now achieve high reliability ($\geq$99.5%) in the entire range of background brightness and source density encountered in the OSV region down to $<$1 mJy in [3.6] and [4.5] bands, $\sim$2 mJy in band [5.8], and $\sim$10 mJy in band [8.0]. The high reliability, however, means that the GPSC will be substantially incomplete.

The GPSA (includes sources with S/N$\geq 5\sigma$) and GPSC (reliability $\geq$99.5%) each contain more sources from the OSV region than 2MASS reported for the same field.

Photometric accuracy in all IRAC bands can be achieved to $\pm$0.2 mag in the entire range of background conditions and source density encountered in the OSV region to magnitude limits of: $\sim 14.0^{th}$ at [3.6]; $\sim 12.0^{th}$ at [4.5]; $\sim 10.0^{th}$ at [5.8]; and $\sim 9.0^{th}$ at [8.0]. The agreement between Martin Cohen's predicted fluxes and the GLIMPSE extracted fluxes for our network of flux calibration stars deviate by 5% or less at fluxes below the saturation limits in all bands.

The GLIMPSE quality assessment based on the OSV data and the GLIMPSE post-BCD pipeline processing is summarized in Table 1. The 3σ detection limit is given in row 1; the saturation limit in row 2; the magnitude at which reliability of the GPSC is $>$99.5% in row 3; the magnitude limits at which $>$90% of the sources within a given magnitude bin deviate by less than 0.2 mag from the true magnitude in relatively uniform background regions in row 4, in complex background regions in row 5, and in all regions in row 6. Complex background regions, as defined in Sect. 4, comprise <5% of the GLIMPSE survey area.

Table 1: Summary: GLIMPSE Quality Assessment

row	band	[3.6]	[4.5]	[5.8]	[8.0]
1	3σ Det. Limit (mag)	15.5	15	13	13
2	Sat. Limit (mag)	6.5	6.5	4.0	4.0
3	R(GPSC)>99.5% (mag)	<14.2	<14.1	<11.9	<9.5
4	PA$\leq 0.2^m$ (low BG) (mag)	$\sim$14.0	$\sim$13.5	$\sim$11.5	$\sim$11.5
5	PA$\leq 0.2^m$ (high BG) (mag)	$\sim$13.5	$\sim$12.0	$\sim$10.0	$\sim$8.5
6	PA$\leq 0.2^m$ (all BGs) (mag)	$\sim$14.0	$\sim$12.0	$\sim$10.5	$\sim$9.0

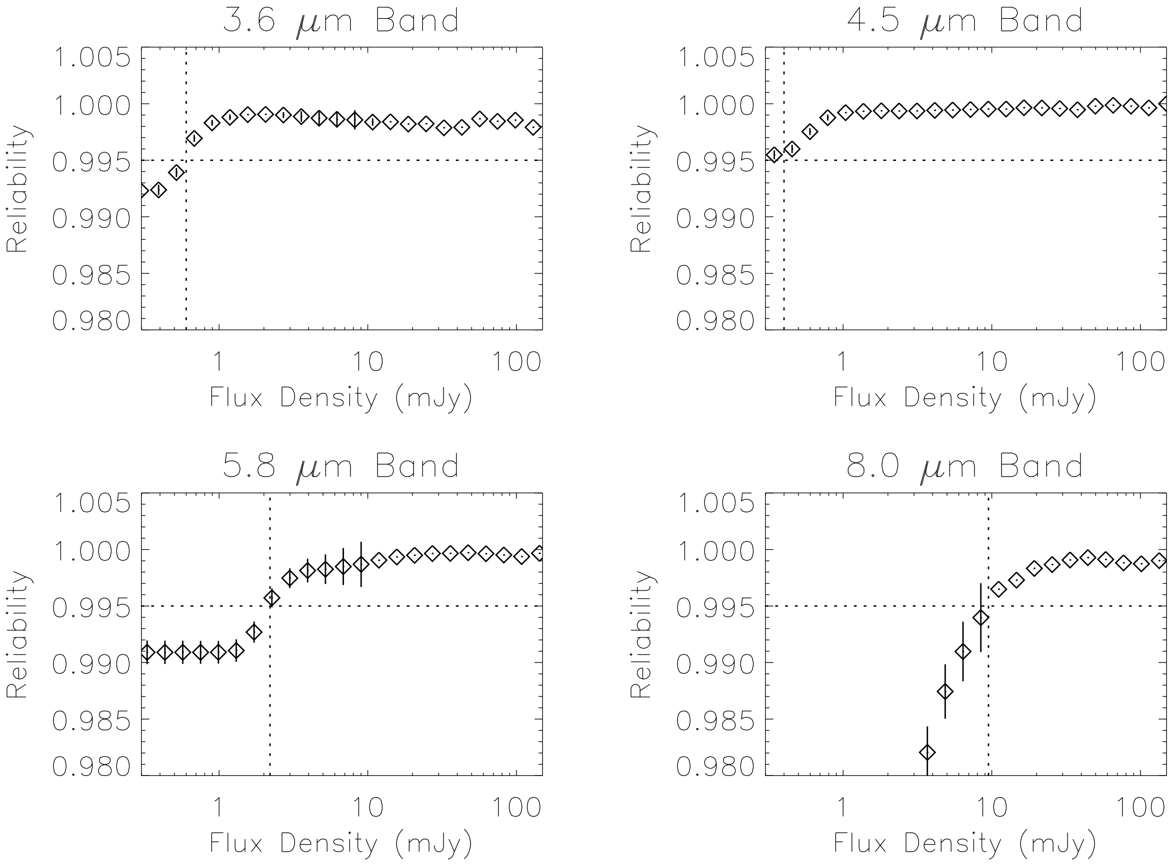

Fig. 1.— The calculated reliability of the GPSC using the OSV data with the constraints discussed in the text. The reliability at 99.5% is indicated by a horizontal dotted lines and the flux density limits at which the reliability is ≥99.5% is indicated by dotted vertical lines. The flattening of the curves in bands [3.6], [4.5], and [5.8] at ≤1 mJy is because there are no sources at these low flux density levels due to the 3σ cutoff and the (2+1) selection criterion.

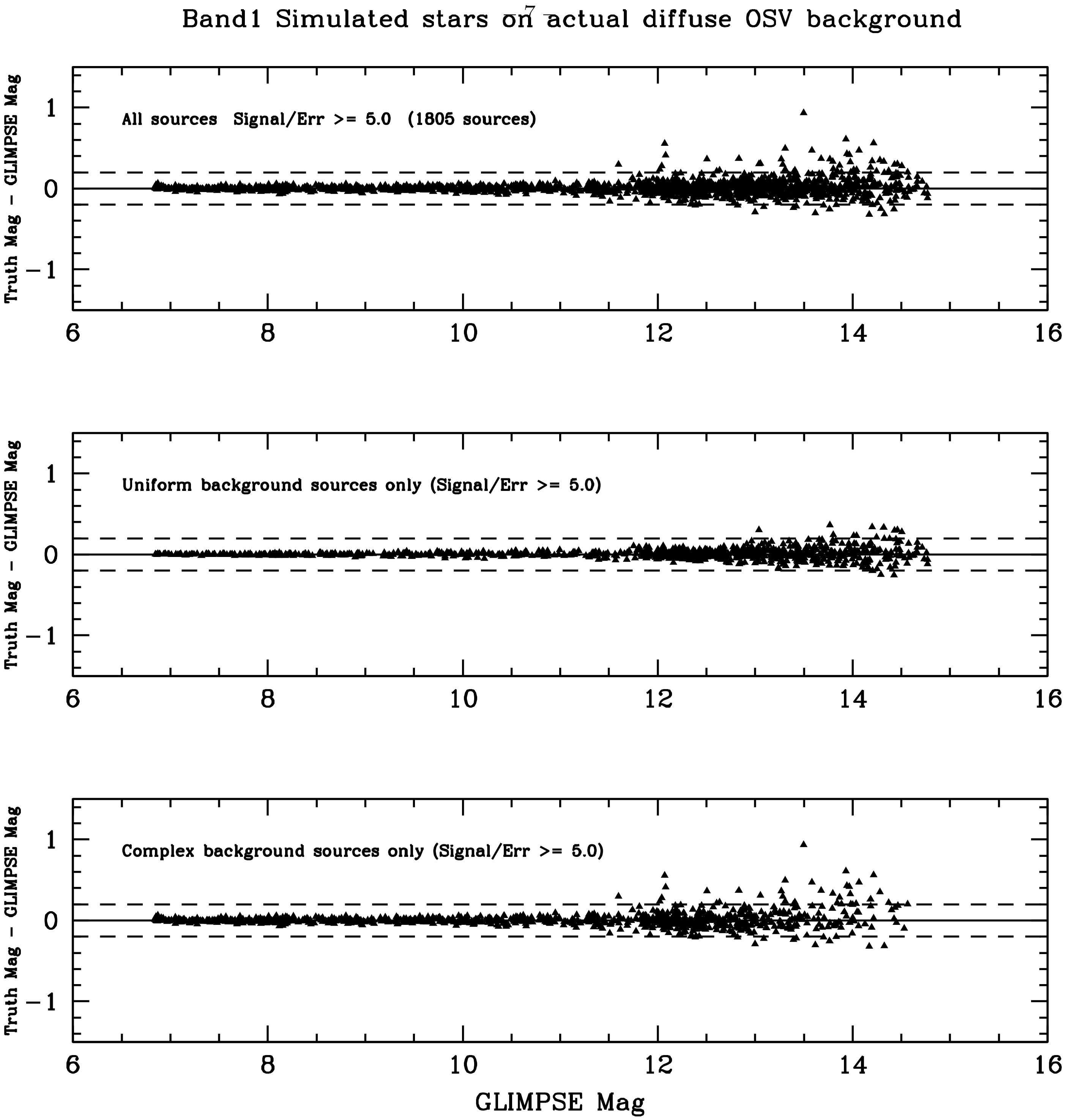

Fig. 2.— The photometric accuracy of GLIMPSE IRAC band [3.6] data using residual OSV diffuse background (i.e., images with point sources removed). Sources with known magnitudes were added to the residual image and extracted using the GLIMPSE pipeline and compared to the true flux densities. The top panel includes all point sources independent of the surrounding background structure. The middle panel includes point sources located in relatively uniform diffuse backgrounds (see text for definition) and the bottom panel includes sources in complex backgrounds (see text for definition).

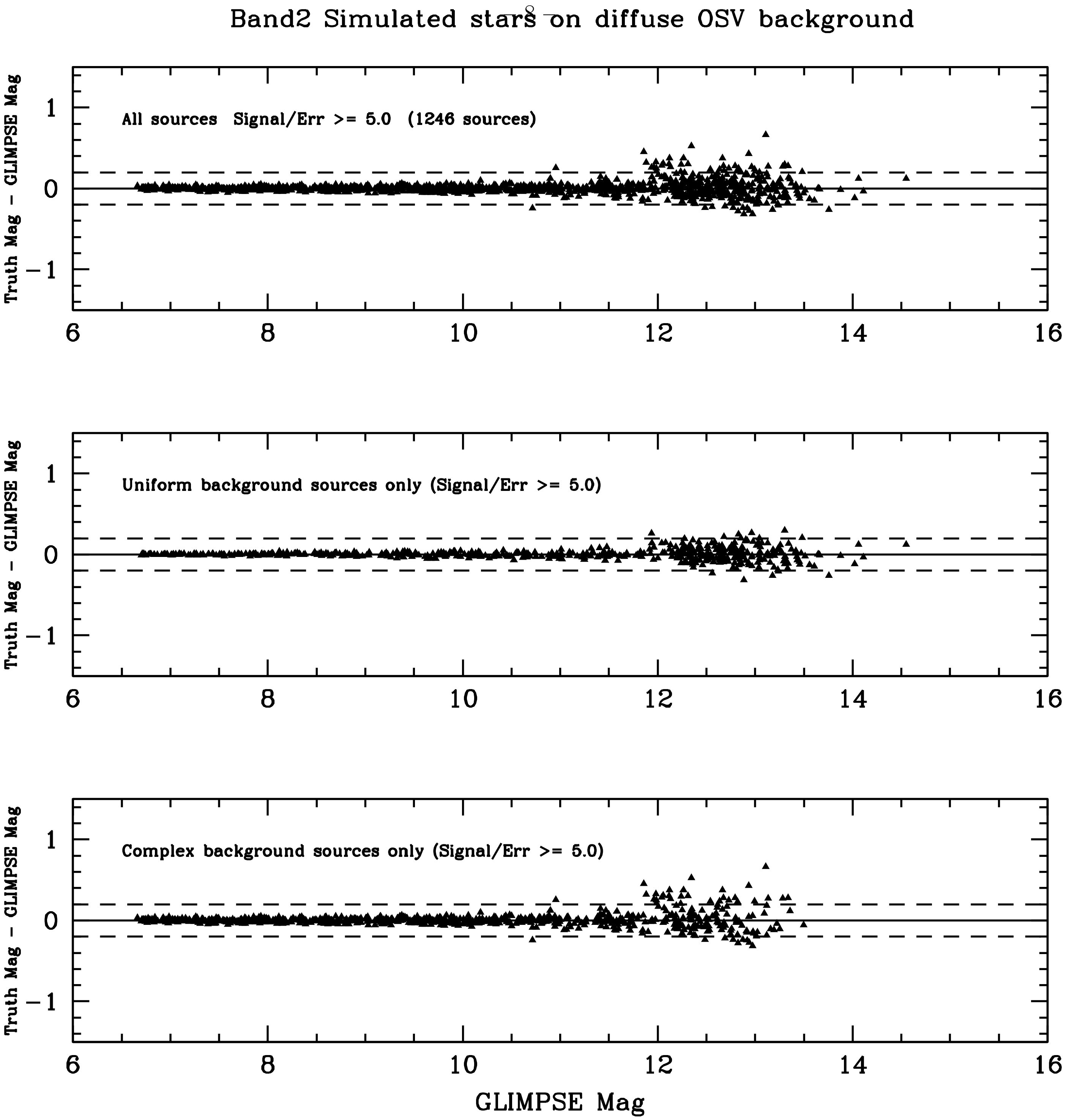

Fig. 3.— The same comparison as in Fig. 2 except for band [4.5].

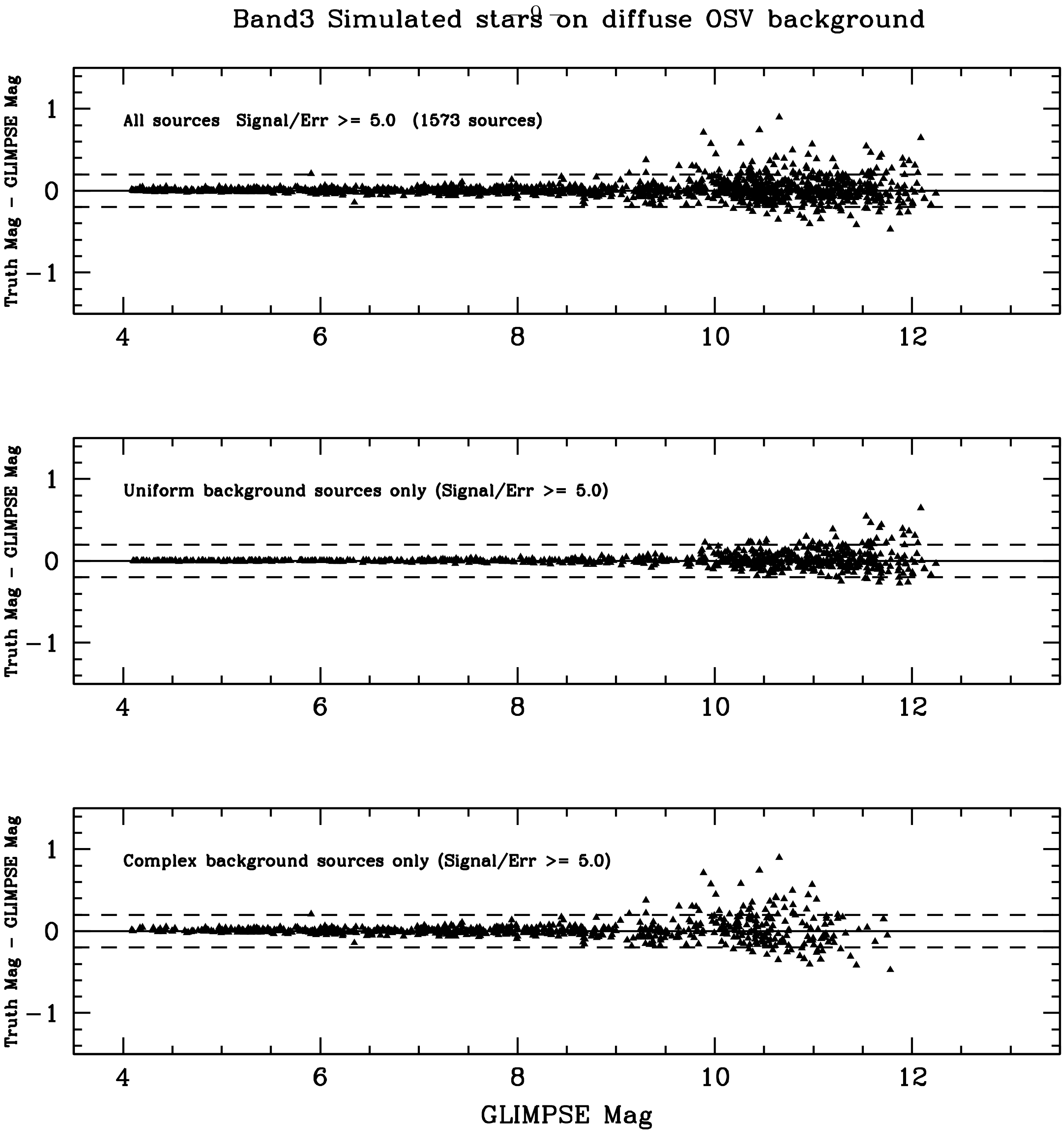

Fig. 4.— The same comparison as in Fig. 2 except for band [5.8].

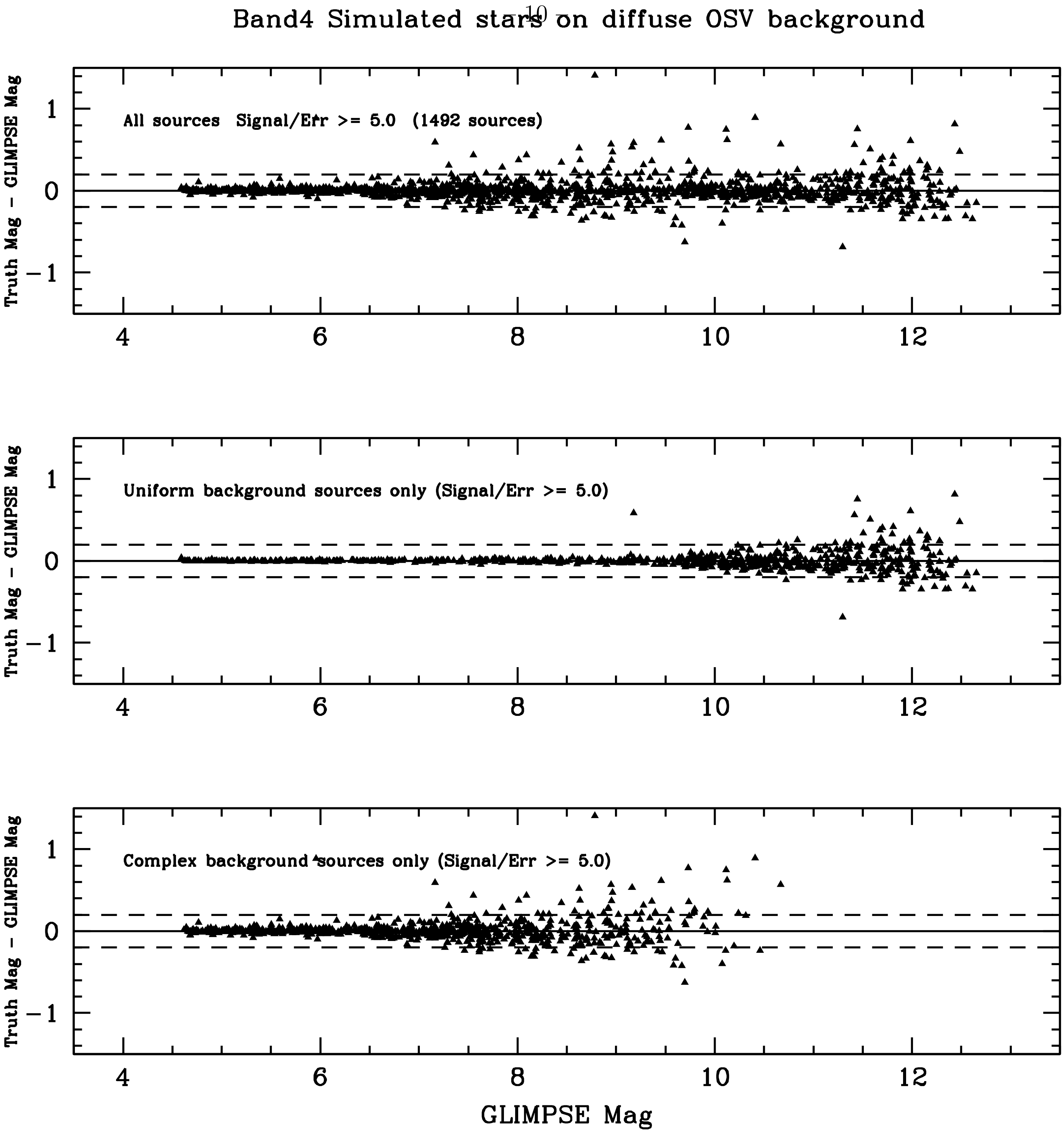

Fig. 5.— The same comparison as in Fig. 2 except for band [8.0].

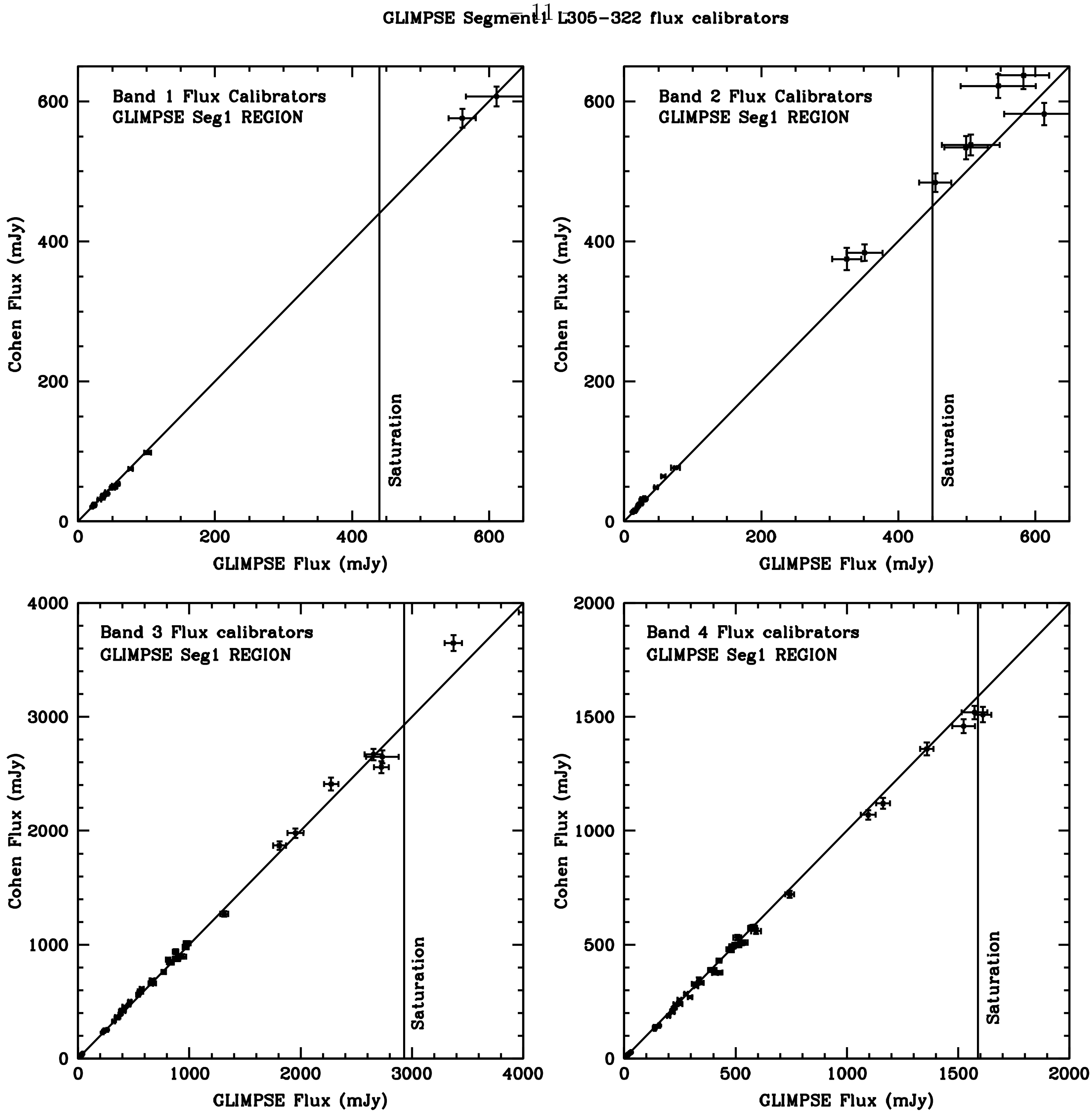

Fig. 6.— A comparison of GLIMPSE extracted flux densities with Cohen's predicted fluxes for our network of flux calibrator stars lying in GLIMPSE galactic longitude segment l=305-322 degrees. The error bars are 1σ for GLIMPSE; the errors for the predicted flux densities of the calibrators are 1σ errors from Martin Cohen (private communication). The vertical line indicates the point source saturation limits for each IRAC band. The panels are upper left, IRAC [3.6]; upper right, IRAC [4.5]; lower left, IRAC [5.8]; and, lower right, IRAC [8.0]. As more GLIMPSE data are processed, these plots will be much more fully populated.